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Revisiting Research on Signal Processing for Communications in a Pandemic

It is difficult to write an *IEEE Signal Processing Magazine* (*SPM*) editorial without acknowledging the presence of COVID-19. I write this editorial from my home office, with a stay-at-home order in effect in Austin. The University of Texas at Austin, like many universities, extended its spring break and then told students to not come back to campus. As others are, I am working to have impactful remote teaching, as well as adjusting to the new realities and its influence on continuing research and service. I am fortunate to have my own computer and a reliable Internet connection at home, not to mention access to water and electricity (which makes working at home more difficult for many around the world).

With so much time at home, I have been thinking about the different ways that signal processing may contribute during this pandemic. Many technical committees are involved in applications of signal processing to the medical field, most prominently the Bio-Imaging and Signal Processing Technical Committee. Medical applications, though, are found in most of the other technical committees in some form.

The direct application of signal processing to virology is already starting to happen. For example, consider the work by *SPM* Area Editor Dr. Matthew McKay. A few years ago, he conducted a research stay at the Massachusetts Institute of Technology in the Institute for Medical Engineering and Science, to study computational immunology. This led to several publications where signal processing tools, such as random matrix methods, sparse principal component analysis, and graphical modeling, are used to provide new vaccine designs for HIV and the hepatitis C virus. Most relevant to current events, Dr. McKay and his team published a paper in the journal *Viruses* that uses genetic data of the COVID-19 virus, together with previous experimental data for the 2003 SARS virus, to identify parts of the COVID-19 viral proteins for which an effective immune response may potentially be mounted, thereby providing early recommendations for COVID-19 vaccine design [1]. This is just an example of which I am personally aware, as Dr. McKay is also a long-time collaborator of mine.

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We are not all fortunate enough to have the right experiences to make direct contributions to virology or the myriad health-care applications using imaging, speech, sensing, or machine learning. With this in mind, I have been thinking about signal processing's role in communications and networking. In short, I believe that research into wireless communications is going to reignite. Yes, I know you might be skeptical since I was a coauthor of an article predicting the demise of research in the physical layer of communications [2], published just before the field was reinvigorated by massive multiple-input, multiple-output (MIMO) and millimeter-wave MIMO.

Everyone is being reminded about the relevance of wireless communications. Internet access is enabling many in the world—like engineers—to work remotely. Most of that access happens through either a wireless local area network connected to a modem providing Internet access or through a cellular network. Many of us are depending on wireless communication to continue with our jobs and stay connected to our loved ones. The current environment shows the relevance of communications and the tangible benefits that may result from further developments in the technology.

In my May 2019 editorial [3], I reviewed key features that motivated the developments of 5G. Some of the objectives for 5G were higher data rates and lower latency. Other objectives were related to 5G's support for new industry verticals like automotive, factory of the future, and of special relevance e-health. I also argued in [3] that all of the goals of 5G were not met, and that motivated the development of 6G cellular systems. It is useful now to reflect on some of the features, objectives, and industrial areas given the current environment.

Ubiquity is not just a fashionable word to decorate an introduction. In the last 20 years, many papers motivated

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research on 4G and 5G wireless communications using the term *ubiquitous communication*. It became a popular phrase for abstracts and introductions. At some point it seemed to be overused, and I banned my students from using it in their papers. I note though, from IEEE *Xplore*, that seven of my papers and articles slipped through the cracks and still used the word *ubiquitous*, not counting this editorial. Of course, it seems that more than 77,000 other papers have used the phrase in IEEE *Xplore*, so maybe now it is a common and accepted term.

In the context of cellular systems, ubiquitous meant having a good cellular connection everywhere—both indoors and outdoors—for all people and devices that want to connect. A communications engineer would refer to this as *good coverage*. This is important in the current environment for remote work, study, socializing, and health monitoring. To have as little disruption as possible, the cellular connection must be available everywhere it is needed. At least in my experience, ubiquitous communication is still far from reality. In some cases, the reasons are based on physics, like penetration losses through concrete walls. In these situations, more base stations, access points, or relays are a natural solution. In other cases, the reasons are based on the limitations of the cellular technology to serve as many users/devices needed in a given cell at the target quality of service levels needed by those devices. Further research in signal processing, communications, and circuits is vital here for increasing the number of users and the amount of spectrum that can be supported.

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High data rates are an important part of ubiquity. In the current environment, higher data rates make it easier for video calls, remote meetings, access to cloud storage, and to stream media (to be entertained after work is done for the day). Low latencies are also relevant for two-way communication to maintain natural pauses when interacting with people.

E-health has many relevant applications to the world of COVID-19. The phrase *e-health* was a catch-all for the many medical applications most unforeseen for 5G, from telemedicine to robotics assisted living. One of the most popular examples of 5G-supported health-care applications was remote surgery. It was imagined that a doctor could control a remote surgical robot that is hundreds or thousands of kilometers away. In a talk, discussion of this application area was often followed by the joke that "as a wireless engineer, I would never allow a doctor to operate on me using wireless." With the prevalence of quarantine and social distancing though, e-health may be the most important and underappreciated of the imagined 5G applications.

Many of us failed to realize the challenges surrounding contagious diseases like COVID-19. In the hospital, it remains critically important to isolate the practitioners from the patients to keep staff well and to prevent cross contamination between patients. Outside the hospital, patients who are infectious but have mild symptoms need to be isolated at home from other household members. Wireless communication can play a role that reduces contact.

Telemedicine is one important application that is supported by wireless communication. With telemedicine, practitioner visits happen remotely, typically via video chat. Telemedicine could be applied in hospitals to reduce contacts during a well-check or as a means to cope with limited numbers of beds. It also helps in keeping infectious patients with mild systems out of the hospital. Naturally, high data rates and ubiquitous service are needed for telemedicine to approach the in-person experience.

Sensing, which also leverages signal processing, could be part of an e-health system. Imagine a telemedicine access point with sensors could be used to aid remote diagnosis and monitoring. Examples of candidate sensors include microphones, cameras, temperature sensors, infrared sensors, or radars, among others. Machine learning could be used to process this sensor data and detect when patients have a temperature, are sleeping well, or how they are walking. Affective computing could be used to detect and monitor emotional state.

Automation may be more than just a means to improve lifestyle. Beyond e-health, two other notable application verticals considered in the development of 5G and were automotive and factories. Both applications have automation as a common theme.

In the automotive case, connectivity like 5G has been proposed to support advanced driver assistance systems and driverless vehicles. Such systems are made possible thanks to many developments in signal processing including sensor fusion, positioning, and machine learning. A number of applications have been envisioned for vehicular systems (some already realized) including forward collision warning, blind-spot warning, self-parking, and platooning. I think, though, that most of us did not think about automotive applications during work-at-home orders.

There are many ways that advanced automotive systems could be used during a pandemic. Robotic ambulances could transport patients to hospitals. Robotic delivery vehicles could drop groceries at the doorstep, make meal deliveries, or facilitate transport of medical samples or supplies. These applications reduce the exposure risks for human drivers as well as the end customers. Of course, the details of proper cleaning and sanitation would still need to be worked out. In any case, automotive systems can have important applications in emergency scenarios and are not just a means to facilitate naps while commuting in the car.

Factory automation principles may not just be for factories. Much of the discussion about factories of the future in the context of 5G was directed toward factories full of robots. The use of wireless communication facilitates rapid reconfiguration, which makes smaller manufacturing jobs more feasible. In the most elaborate of such visions, all of the robots were connected and controlled by a centralized controller eliminating much of the need for human operators. In many factories at present, humans still play an active role in factory operation. As a result, teleoperation and remote presence are interesting to facilitate working from home. Virtual reality could be used to give workers an immersive view of production in the factory. I believe that factories present many particular challenges related to the combination of high data rates and low latencies.

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Let me finish with a short summary. Many of us have been reminded about the importance of wireless communications for our professional and personal lives. We are also more acutely aware of the benefits of advanced wireless technology and the limitations of the technologies we have at present.

Wireless cellular communication has been developing to support many different applications. Much of that vision, though, was not crafted with a pandemic world view in mind. E-health may turn out to be a critical underappreciated application that needs more attention. Further, other applications of automation should be viewed again through a new lens to see how they can support the e-health application. Wireless communications can be better. In the coming years, I think we will see an increase in research support for signal processing for communications as the recognition of the relevance of this works becomes widespread in the world.

References

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